Multiple Large-Scale Bio-Barriers for Large Multi-Contaminant, High-Concentration Plume in Brackish Water

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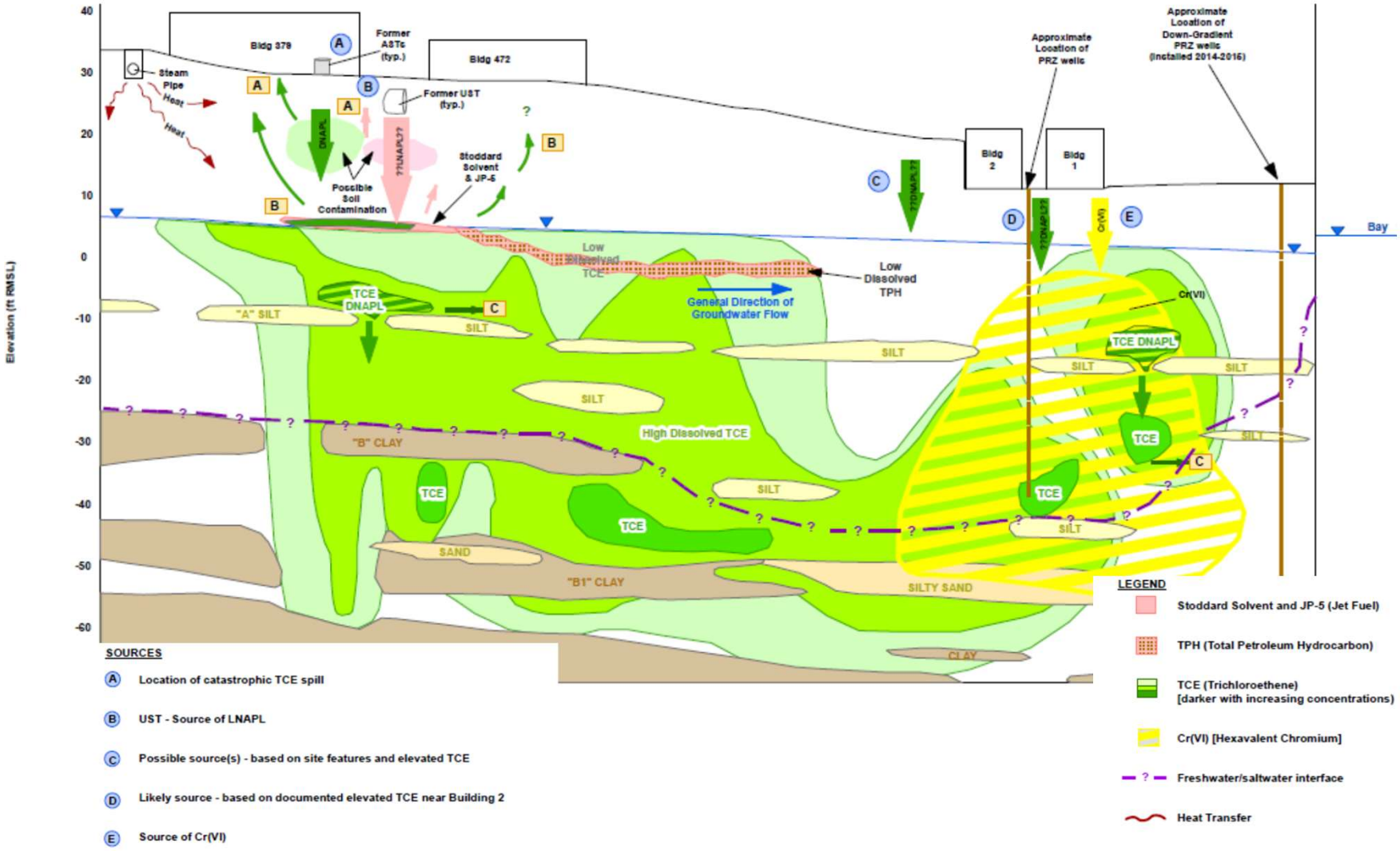
Objective

Present an overview of the effectiveness of multiple bio-barriers used to remediate the downgradient edge of a plume with multiple challenges:

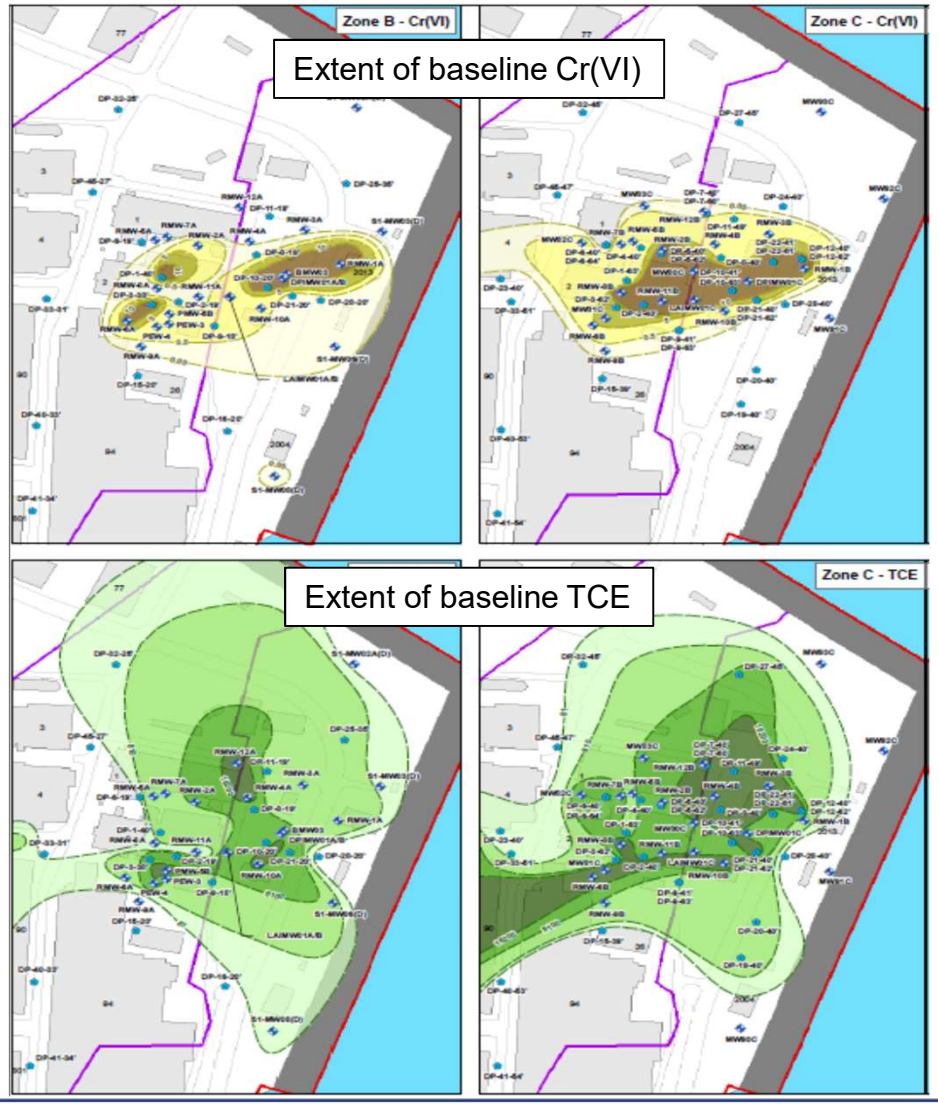
- **Multiple contaminants - cVOCs and Cr(VI)**
- **Elevated levels of contaminants [> 100 mg/L for TCE and > 140 mg/L for Cr(VI)]**
- **Brackish water with high TDS**
- **Complicated lithology in saturated zone**
- **Large/long plume (1/2-mile long, hundreds of feet wide)**
- **Located in a very busy part of NASNI (near two active piers)**
- **Every buried utility that is present base-wide is present in the project area**

Site Background



Site Background

- Elevated Cr(VI) and TCE have been detected in groundwater approaching San Diego Bay
- The contamination is under a high-traffic, utility-heavy part of NASNI
- Plumes are extensive
- Several buildings overly plumes



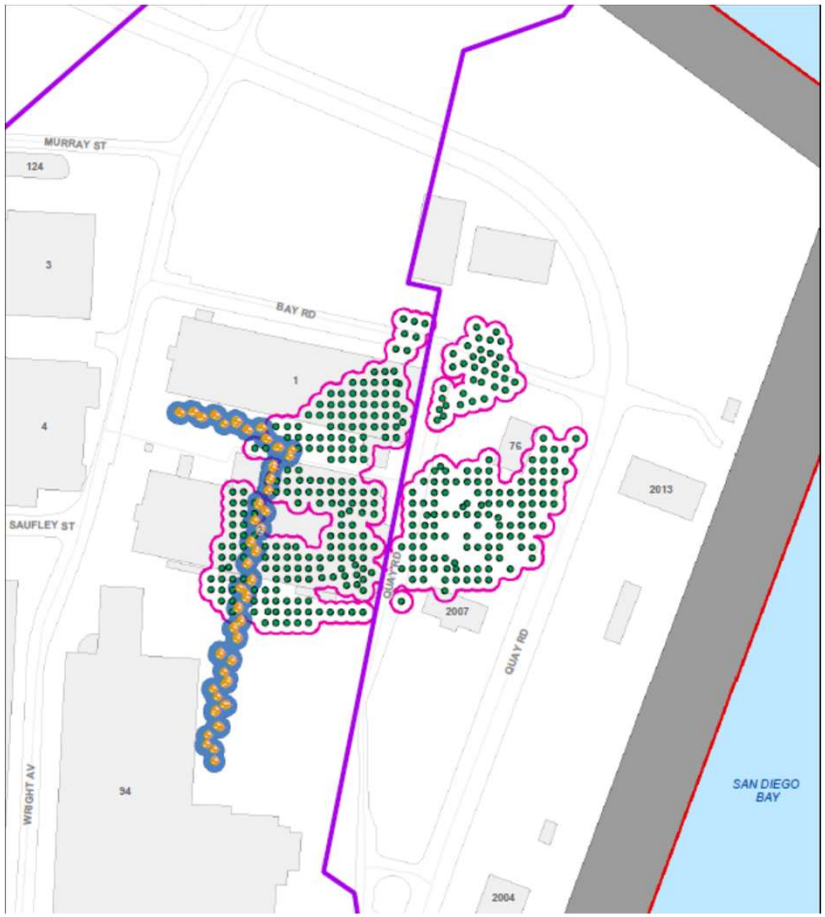
Bench- and Pilot-Scale Testing

Performed limited testing to determine design parameters

- **Bench-scale**
  - –Assessed several organic and inorganic amendments before identifying Emulsified Vegetable Oil (EVO) for bioremediation of cVOCs
  - –For Cr(VI), the SRS® was supplemented with a proprietary abiotic reductant
  - –Bioaugmentation completely reduced Cr(VI) in as little as one day, allowing co-bioaugmentation and complete biological reductive dechlorination of TCE within 35 days
- **Field-scale**
  - –Conducted at three locations each with liquid atomized injection (LAI) and direct-push injection (DPI)
  - –Microbial culture was injected simultaneously
  - –DPI required less distribution time, lower flow rates, and lower pressures
  - –Reduction in TCE was not observed until Cr(VI) concentrations were reduced to under 10 mg/L

Phase I TCRA

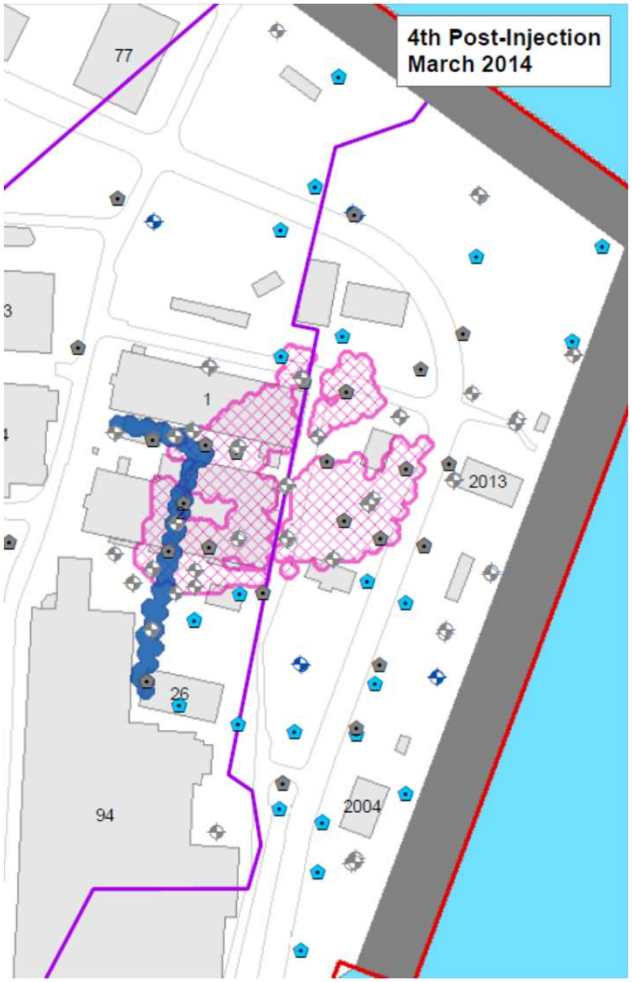
Summary of Phase I TCRA injection activities



- Cut off up-gradient plume into down-gradient plume
- EISB was implemented in 2012 by direct-push injection of emulsified vegetable oil (EVO) at 377 locations
  - Installation and injection into 38 dual-screened injection wells for a 700-foot bio-barrier (UGPRZ)
  - Injection included electron donors (substrate) and microbial cultures (*Dehalococcoides* [DHC] species)

Additional TCRA Characterization

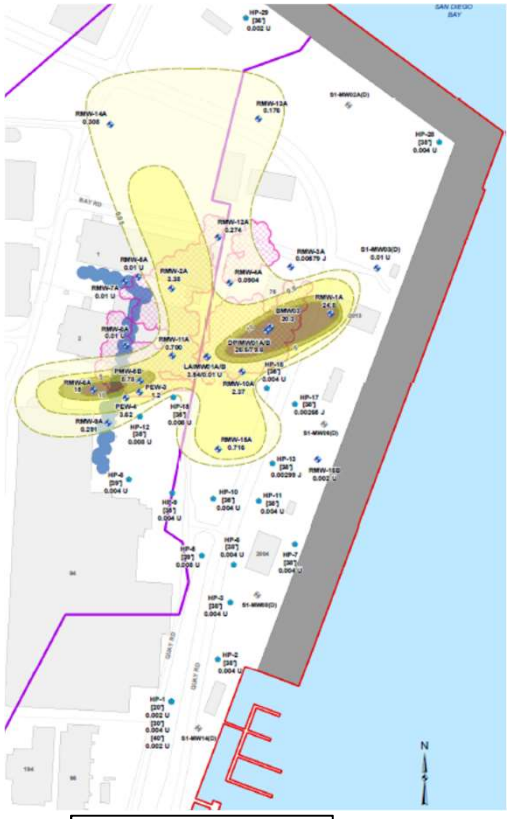
Summary of TAEI Activities



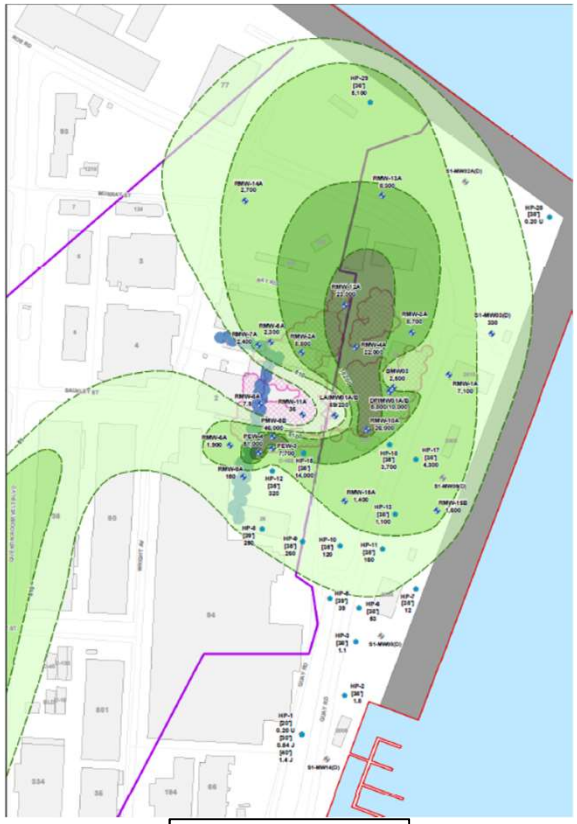
- Regulators raised concerns about Cr(VI)/TCE in other areas
- TCRA Area Expansion Investigation (TAEI) was done to evaluate the extent of Cr(VI) and TCE in groundwater located outside the current treatment area
  - –29 DPT locations for soil and groundwater samples
  - –Installation, development, and sampling of four new paired groundwater monitoring wells

New Monitoring Well
New Hydropunch Sample
Existing Monitoring Well
Previous Hydropunch Sample

Results of the TAEI (Zone B)



Extent of Cr(VI)

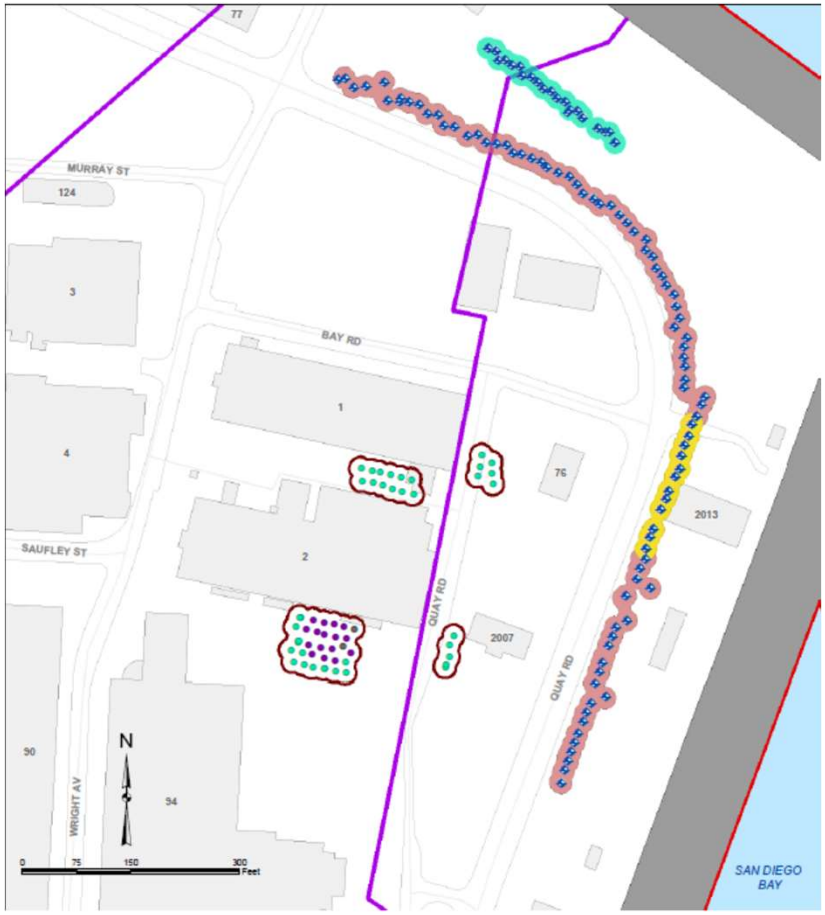


Extent of TCE

Both TCE and Cr(VI) extents were much more than previously thought

Phase II TCRA

Summary of Phase II TCRA injection activities



- Additional action was deemed necessary
- Cone penetrometer testing (CPT) was performed to target specific zones
- Two additional bio-barriers (DGPRZ and DDPRZ) totaling 1,700 feet were added in 2015, and an additional 52 DPI were performed

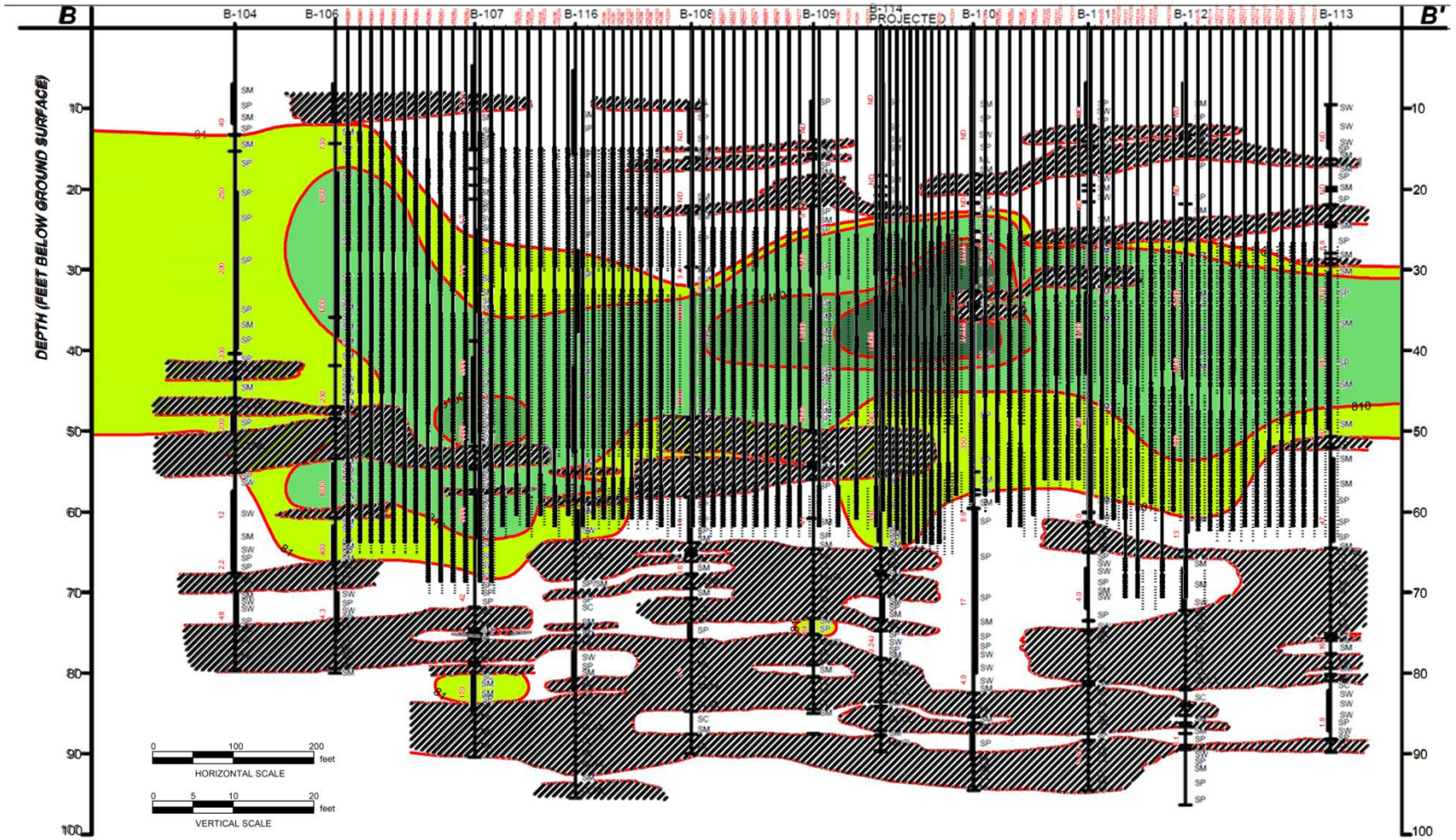
LEGEND

- NASNI Boundary
- OU 19/20 Boundary
- Downgradient PRZ (DGPRZ) and Down-Downgradient PRZ (DDPRZ) Well
- DGPRZ Radius of Influence
- DGPRZ with Lactate Radius of Influence
- DDPRZ Radius of Influence

Direct Push Injection (DPI) Locations

- Slow-Release Substrate (SRS)
- SRS with Zero Valent Iron (ZVI)
- Refusal at Location
- DPI Area (2015)

DGPRZ Injection Strategy

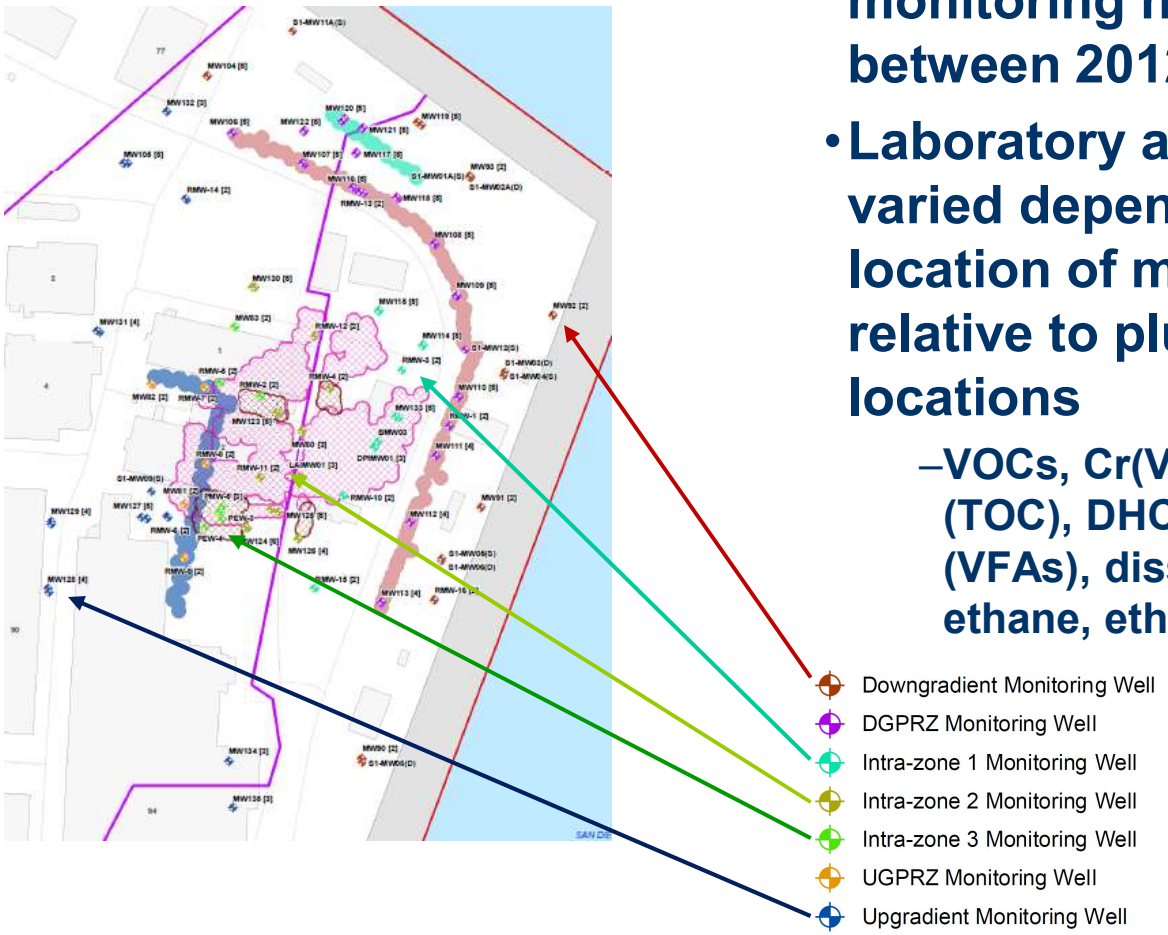


PRZ Recirculation

- Limited recirculation was performed during injection of the DGPRZ
  - In a set of four consecutive locations, the first three locations were injected into while the fourth location was extracted from
  - To maintain integrity of the aquifers, extraction and injection was performed for wells in the same zone
  - Moving downgradient, the location which was previously extracted from was now injected into, along with the following two locations
- EVO was mixed and injected using a Dosatron® dilution device
- Sodium bicarbonate was added continuously at a rate of 0.017 lb/gal, to act as a buffer against possible pH reduction due to fermentation of EVO
- At each depth, EVO + water was injected, followed by anaerobic water (created by mixing recirculation water with potassium sulfate), microbial culture, anaerobic water, and finally, EVO + water

Post-Injection Monitoring Activities

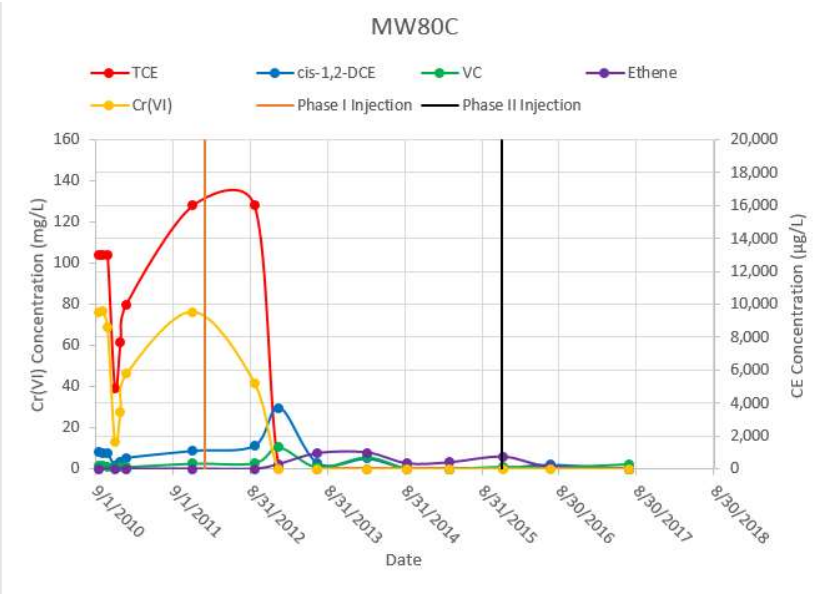
Summary of monitoring well locations



- 9 rounds of post-injection monitoring have occurred between 2012 and 2017
- Laboratory analyses have varied depending upon the location of monitoring wells relative to plumes and injection locations
  - VOCs, Cr(VI), total organic carbon (TOC), DHC, volatile fatty acids (VFAs), dissolved gases (methane, ethane, ethene), nitrate/sulfate

Monitoring Results

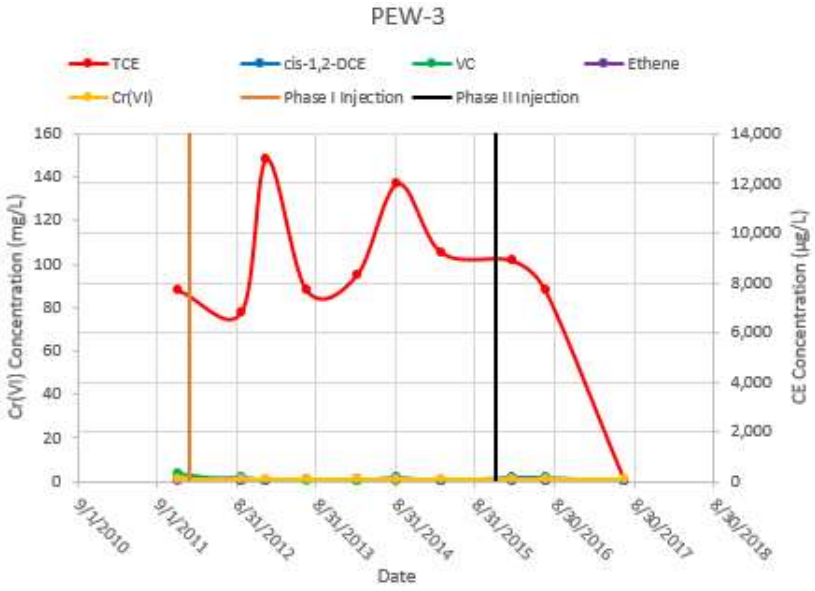
Summary of MW80 (Intra-Zone 2) CE and Cr(VI) Results



- **TCE began to biodegrade following reduction of Cr(VI) to below 10 mg/L (consistent with bench scale findings)**
- **Decreases in TCE correlated with increases in daughter products *cis*-1,2-dichlorothene and vinyl chloride**
- **Similarly, decreases in daughter products correlated with an increase in ethene**

Monitoring Results

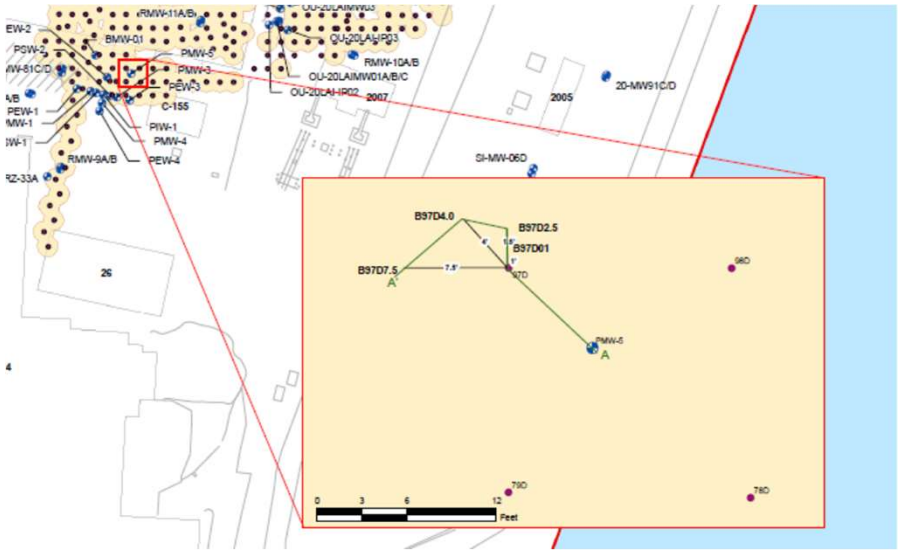
Summary of PEW-3 (Intra-Zone 3) CE and Cr(VI) Results



- **Injection of zero valent iron (ZVI) was conducted in specific areas during Phase II to address recalcitrant TCE concentrations**
- **ZVI enhances biodegradation by rapidly lowering the redox potential of the *in situ* environment**
- **Possesses hydrophobic properties (similar to CEs) which attracts the contaminants**
- **Noticeable decrease in TCE concentrations at PEW-3 following injection of ZVI**

TOC Levels in Groundwater

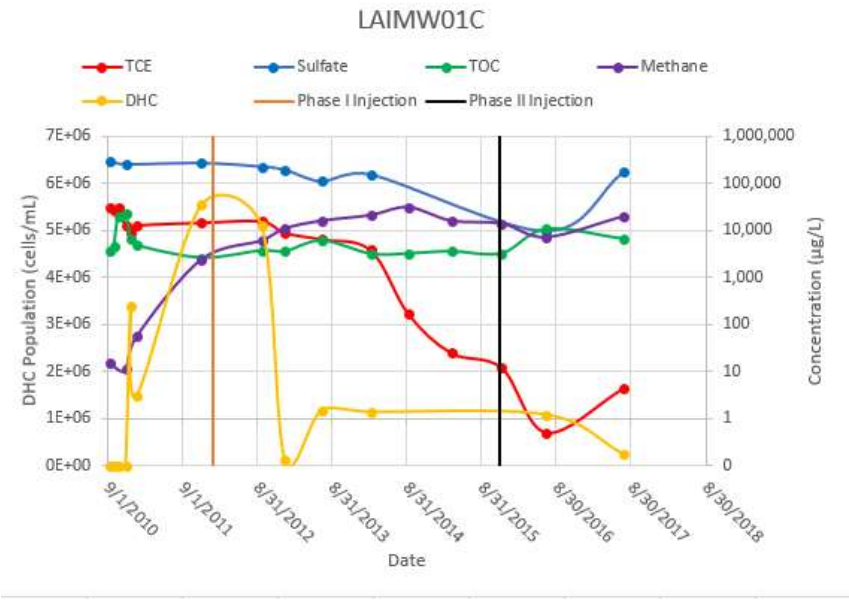
Location of soil investigation samples



- Initial sampling indicated biodegradation was occurring, but TOC was not observed at several locations
- This raised questions about EVO distribution
- Soil investigation to evaluate the extent of the distribution and migration of EVO was performed
- TOC was detected in soil samples, and black-colored soils and fermented EVO odors were noted in all soil borings
- Majority of EVO was sorbed to the soil matrix within a few feet of the injection point, which can serve as a source of dissolved electron donor for several years
- Thus, dissolved TOC in groundwater may not necessarily be a reliable indicator of EVO distribution/efficacy

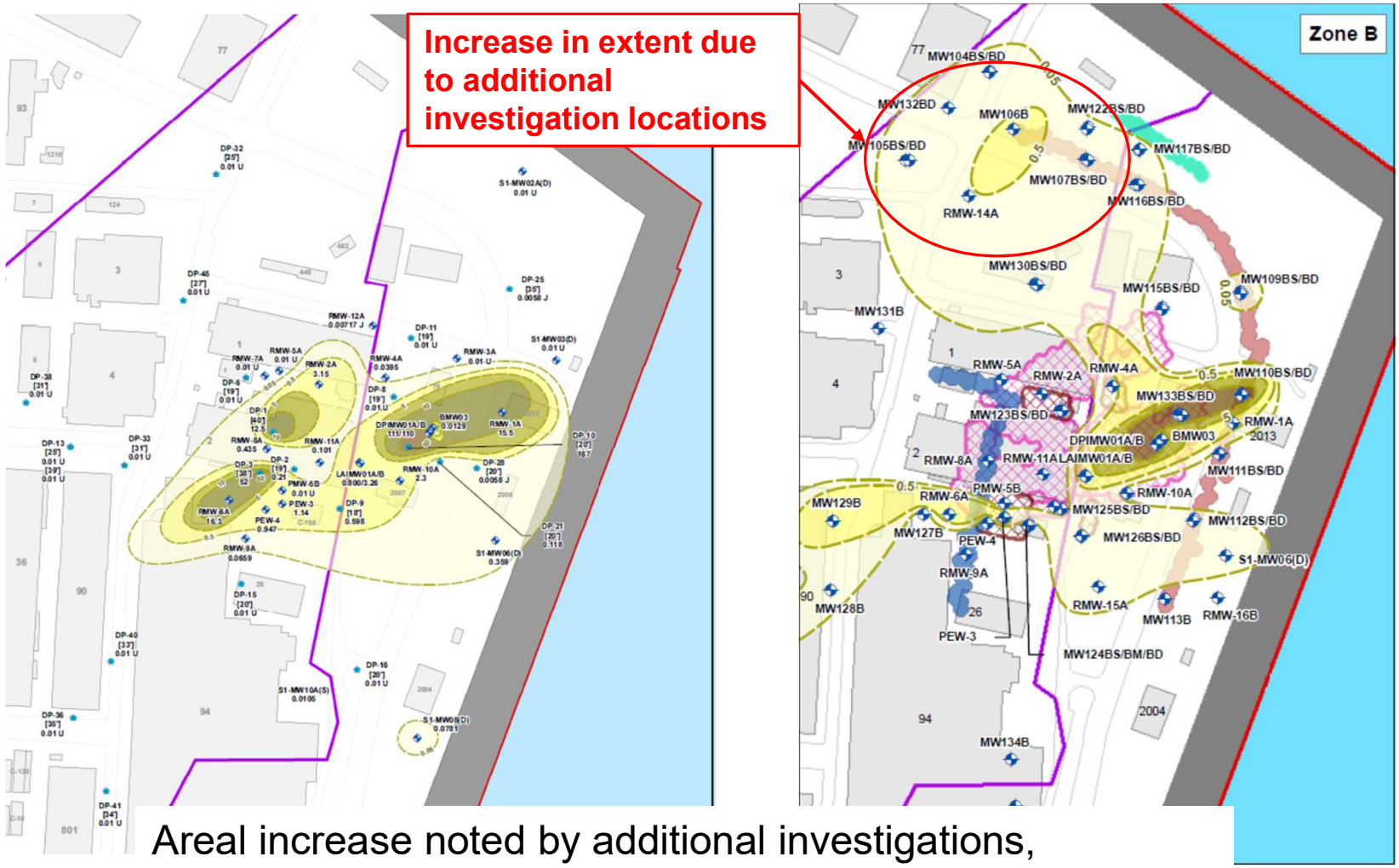
Monitoring Results

Summary of LAIMW01C (Intra-Zone 2) Geochemical Results



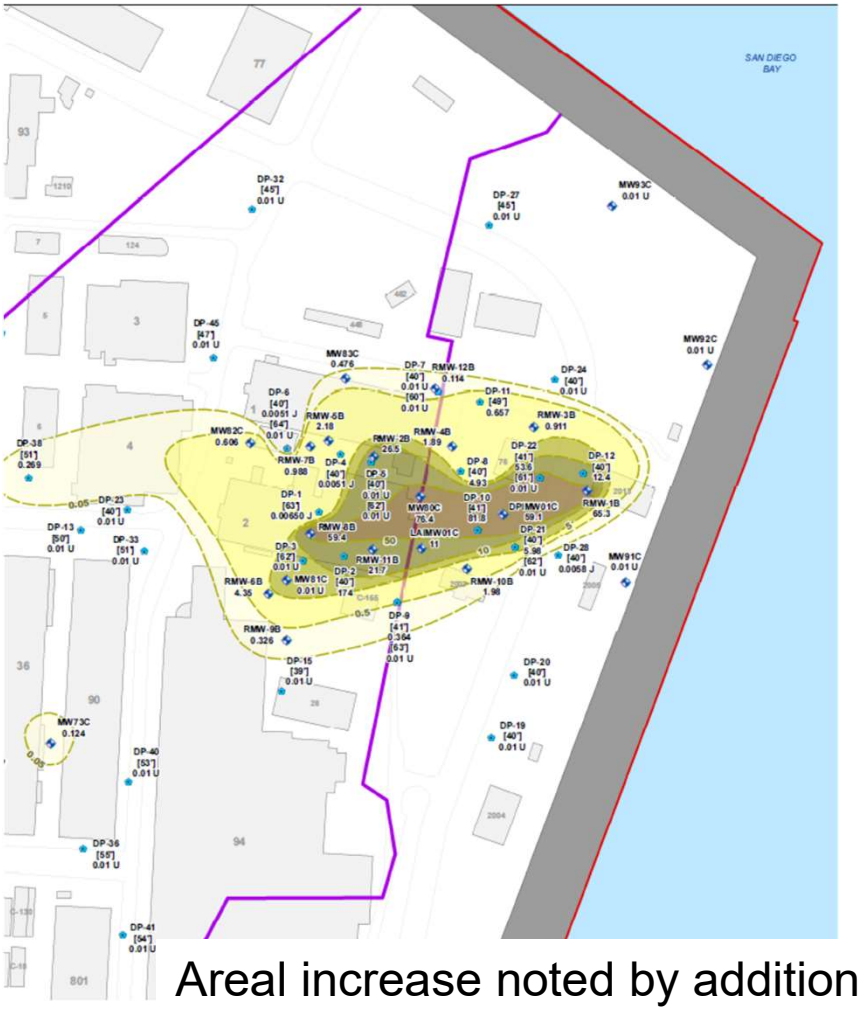
- TCE biodegraded with a robust microbial population (a population >10^4 cells/mL is recommended)
- In a reducing environment, sulfate can be a terminal electron acceptor (reduced to sulfide)
- Good correlation between sulfate and TCE concentrations, as well as microbial population
- TOC used to track presence of the electron donor (EVO), but as mentioned previously, not always a reliable indicator
- Methane is produced when CO_2 is used as a terminal electron acceptor: Strong correlation between increasing methane concentrations and decreasing TCE concentrations

Extent of Cr(VI) Over Time – Zone B



Areal increase noted by additional investigations,
but significant decreases in elevated Cr(VI) concentrations

Extent of Cr(VI) Over Time – Zone C



Areal increase noted by additional investigations,
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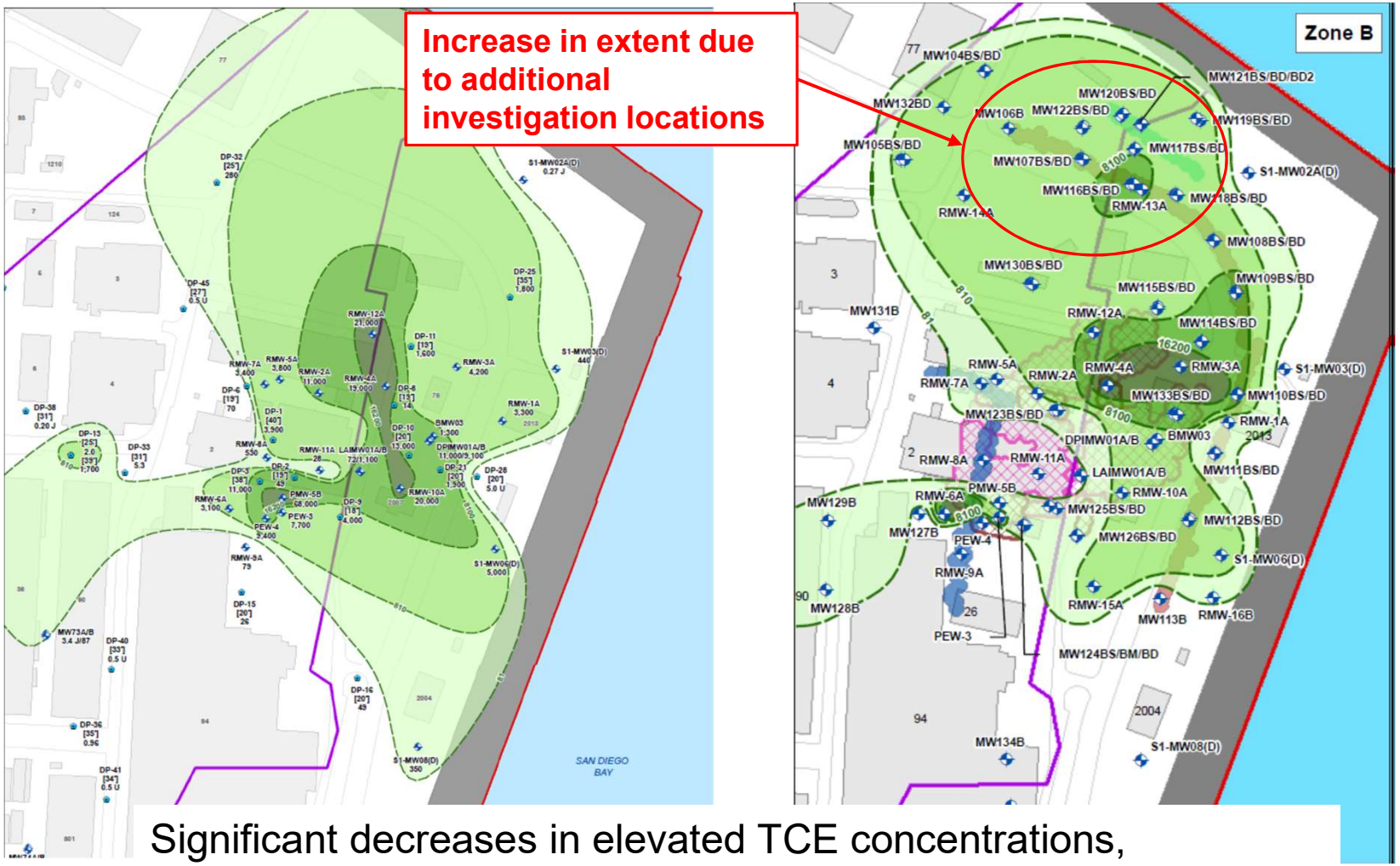
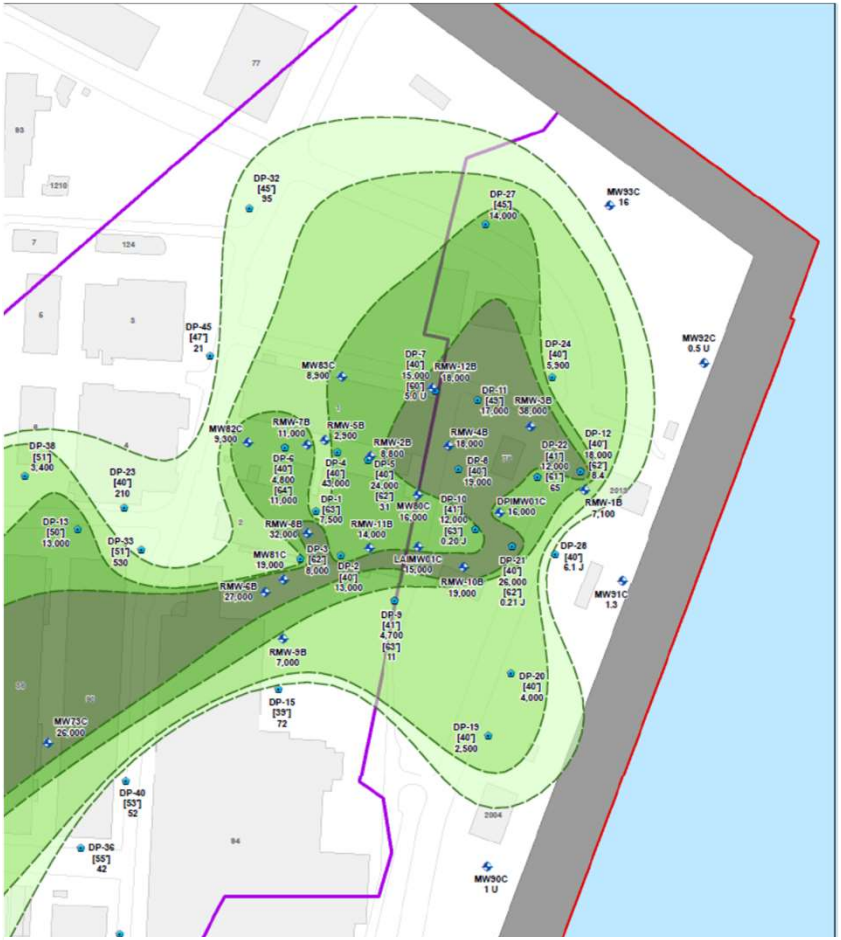
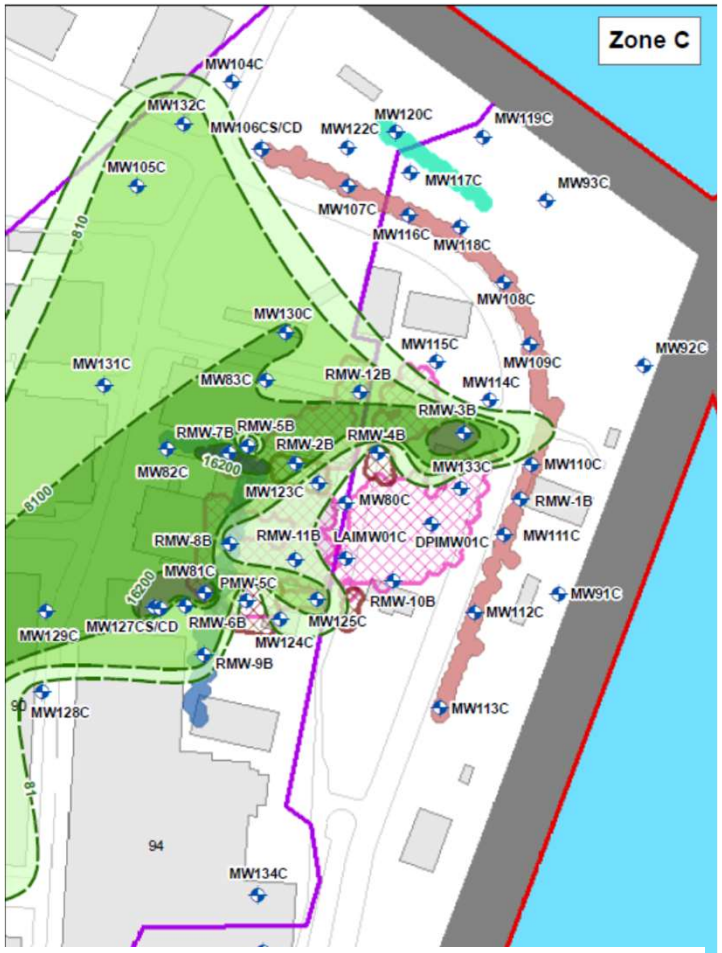
Extent of TCE Over Time – Zone B



Significant decreases in elevated TCE concentrations, and effective remediation of TCE in injection area near Building 2

Extent of TCE Over Time – Zone C





Significant decreases in elevated TCE concentrations,
and effective remediation of TCE in injection area east of Buildings 1 and 2

Knowledge Check

Groundwater TOC results are always the best indicator an organic substrate has been distributed in the aquifer?

a) True
b) False

Bench- and pilot-scale testing should always be considered for developing treatment design?

a) True
b) False

Summary

- EISB was capable of remediating elevated TCE and Cr(VI) [10s of mg/L] in brackish water
- Reductive dechlorination of TCE did not occur until Cr(VI) drops below 10 mg/L
- Addition of ZVI helped to decrease recalcitrant elevated TCE concentrations
- Good correlation between reductive dechlorination of TCE and sulfate/methane concentrations
- TOC is not the best indicator of EVO distribution
- Minimum longevity of EVO in the saturated zone is at least 4 years

Contacts and Questions

Points of Contact

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Questions ?